This paper has been cleared by ASC 99-0720

PRACTICAL CONSIDERATIONS FOR FIXED WING HELMET-MOUNTED DISPLAY SYMBOLOGY DESIGN

Eric E. Geiselman
Air Force Research Laboratory
WPAFB, Ohio

Helmet-mounted displays (HMDs) may become a primary source of head-up information in future tactical aircraft. In evaluations, HMDs have produced improved situation awareness and mission performance. To realize this improved performance, HMD equipped pilots spend significantly more time looking off-axis, away from traditional displays. Accordingly, it is important that HMD information be designed so targeting and ownship status symbology is effective and safe. The U. S. Air Force Research Laboratory is working to develop an optimized HMD symbology set. Toward this end, symbol designs must accommodate the conditions of intended use, technology limitations, and integration with other displays. This paper discusses efforts to design target tracking/location and ownship status symbologies for the day/night all weather fixed-wing tactical aircraft application. Design principles derived from both laboratory and flight test are presented. These principles relate to symbology frame of reference, orientation, compression, and line of sight mechanization. Evaluation methodologies are also discussed.

INTRODUCTION

Helmet-mounted display (HMD) technology will be fully integrated into next-generation tactical aircraft. Although laboratory research and flight evaluations have consistently demonstrated the potential for HMDs to enhance tactical situation awareness (SA) and improve mission performance, the exact utility of HMD technology can not yet be stated confidently. On one end of the spectrum, the HMD may simply provide an aimsight reticle and symbology for purposes of target cueing and sensor guidance. The other end of the spectrum sees the HMD as a complete replacement for the head-up display (HUD) and the primary source of all head-up information (as in an encapsulated cockpit). Because each end of the spectrum has its respective advantages and disadvantages, the evolution of the HMD will probably lie somewhere between these extremes. The challenge to the designer tasked with determining the information content and functionality of the HMD is to ensure that the technology provides the correct information for the pilot at the correct time. This is achievable through a systematic design and validated evaluation approach.

This paper describes ongoing efforts of the Air Force Research Laboratory (AFRL) Visual Display Systems Branch toward optimizing the HMD presented information in order to enhance mission performance and survivability for near-term HMD technology applications. The rationale and associated design decisions presented here are based on previous research, flight test feedback, and the hardware configuration of the first HMDs likely to be operationally fielded. It is intended also that the design principles presented here generate research interest and, maybe most importantly, initiate research with opposing hypotheses. The following paragraphs first discuss several generalizations we use as the basis for HMD symbology design. Next, sample symbology candidates and the principles under which they were designed are presented. Included is HMD resident target location and ownship status symbology. Finally, several recommendations related to the empirical evaluation of HMD symbology are offered.

HMD Functionality

The primary purpose of the HMD is to provide target acquisition information to the pilot and for the pilot to provide target cueing information to the aircraft. HMD resident information should first be designed to get the pilot's eyes on a target and lead a sensor to a point of interest (POI). In parallel arise both the capability and perhaps the need to provide other types of information via the HMD. For instance, the HMD affords the unique capability to present ownship status information (including airspeed, altitude, heading, and attitude) to the pilot regardless of head location or movement relative to the aircraft axes. Ownship status presented to the pilot off-axis (other than along the aircraft flightpath) may be very useful in degraded visual conditions and at night.

A primary HMD symbology development objective is the determination of how different information categories will work together, as well as with other cockpit displays. The HMD offers a new coordinate reference frame for which information needs is related. This is both a challenge and an opportunity for the designer to exploit the unique symbology

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1999**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **Practical Considerations for Fixed Wing Helmet-Mounted Display Symbology Design**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Air Force Research Laboratory Wright Patterson AFB, OH 45433-7022**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**5**	

functionality afforded by a head-coupled coordinate reference frame.

Previous research and flight test feedback

From a review of previous research and flight test feedback, the following conclusions are reasonable:

1) HMD presented information, compared to HUD-only information, enables (or compels) pilots to look farther off-axis (off-boresight) for longer periods of time during air-to-ground and air-to-air tasks. (Osgood, Geiselman and Calhoun, 1991; Geiselman and Osgood 1994).
2) Effects of duration and angle off-axis are seen independent of information category (target information vs. ownship status) (Geiselman and Osgood, 1994; Geiselman and Osgood, 1995).
3) Pilots prefer off-axis ownship status information be included within the HMD symbology set. (Osgood et al, 1991; General Dynamics, 1992; Boehmer, 1994; Geiselman and Osgood, 1994; Osgood and Chapman, 1997; Fechtig, Boucek, and Geiselman, 1998).
4) Specific symbology formats intended for use in the air-to-air arena should be designed to minimize the visual area they occupy (Fechtig, et al, 1998).

It appears that any information presented on the HMD may compel the pilot to look farther off-axis for a longer period compared to the same task performed without HMD presented information. This may result in increased targeting SA, but the effect on the spatial orientation component of overall SA is not yet known. It is important that we avoid increasing targeting performance only to accrue a cost elsewhere. Based on these findings, the symbology design principles presented in the following paragraphs have been derived. Once these principles have been validated, along with others, it is intended that they be included in design guidance documentation such as Mil-Std-1787C.

TARGET LOCATOR LINE DESIGN

The purpose of the target locator line (TLL) is to indicate the relative azimuth and elevation vector between a fixed point of reference on a display field of view (FOV) and some POI outside the display FOV. Locator lines have been used with great success as a HUD convention as well as during HMD demonstrations and operational flight test.

A properly designed and implemented TLL symbology can help the pilot to quickly and intuitively perform a visual location task. Design features can be added to the locator line to provide additional information such as angular distance between the center of the HMD FOV and target. Also, target identification information can be included in the TLL mechanization. The basic TLL indicates the combined azimuth and elevation to a POI, but it does not show the angular distance to the same point. Angular distance is indicated in the HUD via a digital readout attached to the locator line.

The HUD TLL is mechanized to indicate the location of the POI relative to the nose of the aircraft. The HMD resident TLL is mechanized to indicate the location of the POI relative to the nose on the pilot's face. This "look-to" TLL orientation has to indicate angular distance changes relative to head movement rates of change compared to the much slower rates produced either by target or ownship maneuvering. The look-to line frame of reference causes it to be affected by any individual or combination of ownship, target, and/or head movement. Given that the head can move up to 800 degrees per second, a digital depiction of angular distance is not appropriate. Figure 1 is an example of how the digital mechanization would appear if the convention were applied to a HMD. An analog display of angular distance is better suited for the look-to oriented TLL because it indicates rate and trend information, but the accuracy of the digital information is absent. Digital-like accuracy and analog trend features are both desirable because the task dependent use of the symbology can support both ballistic head movement and continuous tracking behavior. Figure 2 shows a TLL with only analog angular distance information. In this example, the arrow grows or shrinks as a function of angular distance. The longer the line, the farther the POI is from the center of the display FOV. Alternatively, Figure 3 shows a reflected cue TLL designed to support instantaneous interpretation as well as continuous tracking behavior. Additional information can be added to this design by shape coding the cue to indicate target identification or some other meaning.

The "reflected" cue slides along the line relative to changes in angular distance. In this case, the reflected cue moves toward the edge of the display FOV as the HMD FOV and POI converge. This mechanization ensures that the observer's attention is drawn toward the area where the POI will appear instead of toward the center of the display FOV. The reflected cue also acts as a instantaneous indicator of angular distance by its relationship to a constant radius locator line. The length of the drawn line represents the angular distance beyond the display drawing surface. The location of the cue on line shows the relationship of the POI to the center of the display FOV and the area beyond the display. For instance, with omni-directional tracking capability, the POI can be located up to 180 degrees from the center of the display FOV. The locator line is used to represent this 180 degrees minus its own subtended angle (the display drawing surface is equal to the radius of the display FOV). In a case where the locator line subtends 10 degrees (20 degree FOV), the line represents the 170 degrees beyond the display. The location of the reflected cue at the halfway point on the drawn line represents a instantaneous angle of 85 degrees from the center of the display FOV (170/2 = 85). Empirical studies have shown this mechanization to support improved target search and tracking performance (Geiselman and Tsou, 1996; Craig, Marshall, and Jordan, 1997).

The following HMD resident locator line design principles have been derived from previous research and operational experience:

1) There should be only one TLL presented at any one time within the HMD FOV.

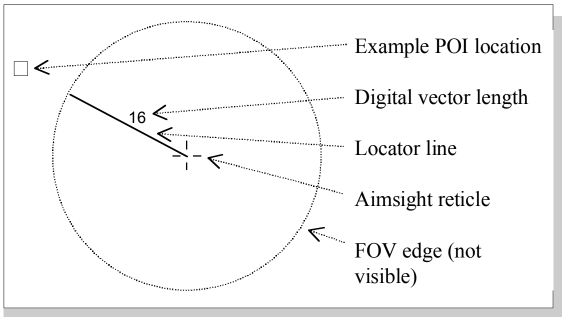

Figure 1. TLL with digital angular distance indication.

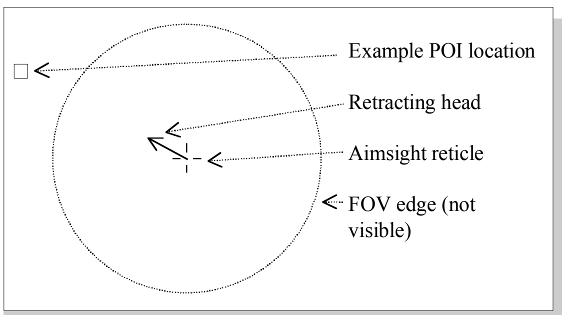

Figure 2. TLL with analog angular distance indication.

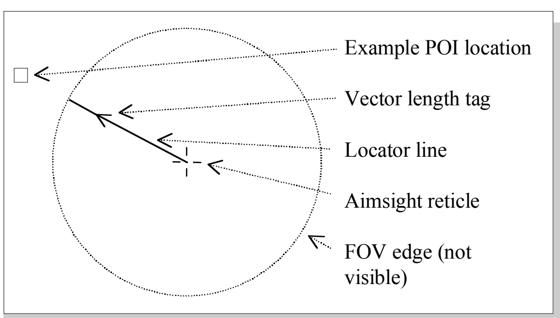

Figure 3. TLL with reflected cue angular distance indication.

2) The mechanization of the TLL should be look-to oriented.
3) The TLL should be anchored to the center of the HMD FOV. This is intended to give the observer a consistent ability to locate the line symbology among display and background clutter.
4) The target locator line should maintain a constant radius within the HMD FOV. This will support both the anchor principle as well as indicate the edge of the display FOV.
5) Symbol compression should be used to indicate the relative angular distance between the HMD FOV and the target location.
6) Indications of closure should move toward the edge of the FOV (reflected cue).

HMD OWNSHIP STATUS DISPLAY DESIGN

Because HMD-equipped pilots tend to look farther off axis for longer periods of time versus HUD-only pilots, it follows that the HMD should contain the information to which the pilots would otherwise attend when they look forward into the cockpit. Ownship status is an example of this type of information. For our purposes, ownship status information is intended to keep the pilot informed of the primary flight parameters while performing targeting tasks. It is further intended to keep the pilot from becoming spatially disoriented and is not intended to be used to recover from incidences of spatial disorientation. Included as information is airspeed, altitude, heading, and attitude. This information is most useful during low light and degraded visual conditions. The challenge to the designer is to develop symbology that supports the information objectives without adversely affecting the primary use of the HMD. This means the symbology has to be highly usable for the associated cost and clutter. It is not acceptable that HMD ownship information cause spatial disorientation or any other significant detraction from the primary objective of the information source.

The following are general ownship status symbology design principles which have been derived from empirical research and flight test feedback. Included are two figures intended to represent symbol set designs both in (Figure 4) and not in (Figure 5) compliance with the following principles.

1) Off-boresight ownship status information should be included in the HMD FOV any time visual conditions are less than day visual meteorological conditions.
2) The information should include ownship airspeed, altitude, heading, attitude, and possibly acceleration and vertical velocity.
3) The purpose of off-axis ownship information is to keep the pilot aware of state changes in support of the primary HMD tactical functions. The display is intended to keep the pilot from entering an unusual attitude vs. allowing the pilot to recover from an unusual attitude while performing off-boresight viewing.
4) To reduce clutter within the small HMD FOV, it is acceptable to use digital information. This supports the reduction of attentional capture.
5) Digital information should be used sparingly and in such a way that its spatial location helps convey meaning or identification. For instance, airspeed should be located left of altitude and heading should be displayed between

airspeed and altitude. Figure 4 shows digital information used to form the ownship reference symbol for the attitude symbology. The basic “T” primary flight information format convention is maintained.

6) Ownship information should be kept in close proximity to other ownship information. The figures demonstrate the effect of non-distributed information (Fig. 4) vs. distributed information (Fig. 5). This is done to reduce clutter and promote space-based attention. In Figure 5, clutter is spread across the display surface and a wide scan pattern is required to sample the required information.
7) To reduce occlusion of POI in the outside world, ownship type information should be located in the bottom portion of the HMD FOV for the air-to-air application and in the top portion of the FOV for air-to-ground applications.
8) Attitude information should support maneuvering throughout the aircraft performance envelope for each axis. The attitude display or ownship information set should not be limited relative to the aircraft capability, and roll, pitch, and yaw movements should be indicated. The attitude reference in Figure 4 represents a total 180 degrees of climb/dive (C/D) angle compared to the total of 5 degrees C/D angle represented in Figure 5.
9) To reduce clutter and maximize usability, the attitude reference should be compressed (a ratio of visual angle subtended by the symbology to the angle represented by the symbology). This allows aircraft maneuvering to be displayed via a global display. High compression ratios promote enhanced interpretation by slowing the apparent motion of dynamic effects, but they reduce precision. The attitude reference in Figure 4 represents a total 180 degrees of C/D angle compared to the total of 5 degrees C/D angle represented in Figure 5.

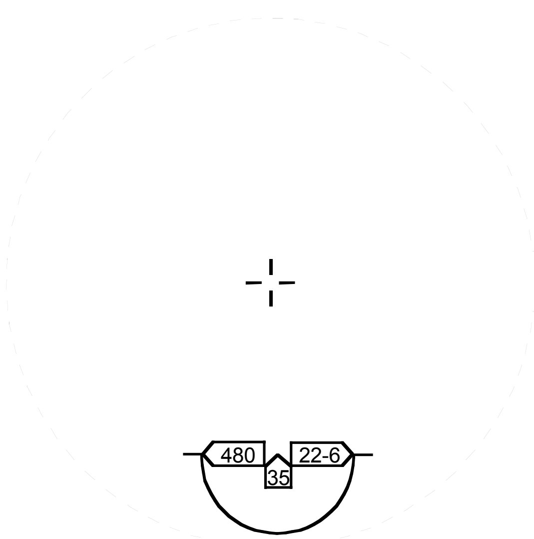

Figure 4. Non distributed ownship status symbology.

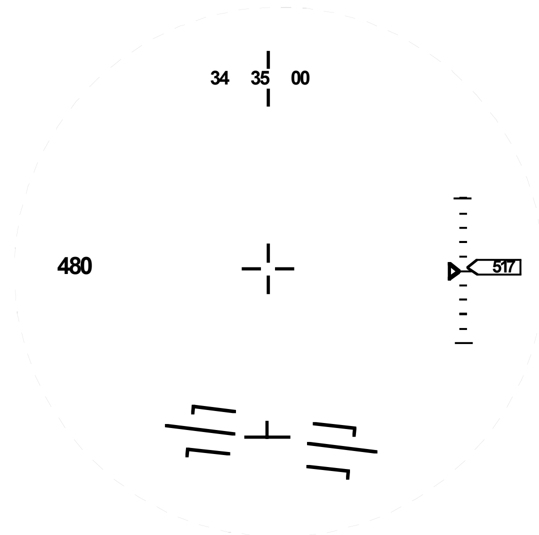

Figure 5. Distributed ownship status symbology.

10) The HMD attitude reference should be flight-path based. This mechanization gives the most meaningful account of the aircraft energy state and instantaneous changes in altitude.
11) Attitude information should be forward referenced. This is done to reduce the potential of disorientation caused by coupling head and aircraft movement with attitude display changes. Forward referenced displays are also easier to “look around” versus information that is superimposed over the outside world. Additionally, forward referenced displays are not affected by tracker system lags and delays.
12) The observer perspective interpretation should be inside-out.

EVALUATION METHODOLOGY

The following are recommended HMD symbology evaluation methodology guidelines intended to be used for symbology design principle validation purposes. Similar to the symbology development, held constant across the methodology design is the belief that the primary purpose of the HMD is target cueing. Therefore, representative evaluation tasks are those which include off-axis target searching, designating, and tracking. Evaluation methodologies should be designed to be flexible so future candidate symbologies and other interface technologies, such as multi-sensory displays, can be reliably compared to previously collected data. A second major objective is to develop a methodology that is both empirically and operationally valid. It should be experimentally controlled but recognized by subject matter experts as operationally relevant. The methodology should include the following features (see Geiselman et al, 1998):

1) A multi-phased trial approach should be used to help ensure trial continuity. Each trial should be formed of separate phases which are treated and analyzed as separate tasks.
2) A dual task paradigm should be employed with off-axis targeting (search, location, designation, and tracking) primary tasks.
3) The secondary tasks include flight tasks such as attitude maintenance, maneuvering, and extreme attitude maneuvering.
4) Because of the operational nature of the tasks, at least the initial evaluations should use subject matter experts as experimental subjects.
5) Independent variable manipulations should include symbology format type, a no HMD symbology baseline condition, and natural horizon presence (on or off to simulate non-degraded and degraded visual conditions).
6) Measurement metrics should include task performance, subject behavior (head movement), and subjective feedback. Subjective feedback should include preference questionnaires, workload estimates, and situation awareness ratings.

CONCLUSION

The near term (within five years) AFRL goal is to develop a performance-optimized HMD symbology set intended for present technology. Toward this end, the approach includes the identification of empirically derived design principles which can be applied across diverse HMD applications. The resulting symbology will form the baseline design for the first operationally fielded HMDs. Likewise, the symbology formats will be included in design guidance documentation for related applications. After the baseline symbology set is established, new designs will be added or will replace baseline designs whenever operational need, technological innovation, or demonstrated performance enhancement warrants the change. Regardless of the eventual HMD symbology format, the derived design principles should help ensure that the symbology functionality is consistent across applications. A somewhat standardized evaluation methodology will help ensure that reliable comparisons of various symbol set candidates are made.

REFERENCES

Boehmer, S.C., (1994). X-31 helmet mounted visual & audio display (HMVAD) system. *Helmet- and Head-Mounted Displays and Symbology Design Requirements.* Lewandowski, R.J., Stephens, W., and Haworth, L.A. (Eds.), The International Society for Optical Engineering. Bellingham, WA., pp. 150-160.

Craig, I.R., Marshall, A.A., and Jordan, C. S. (1997). An evaluation of a methodology to develop future helmet-mounted display symbology. *Head-Mounted Displays II.* Lewandowski, R.J., Haworth, L.A., Stephens, W., and Girolamo, H.J. (Eds.), The International Society for Optical Engineering. Bellingham, WA., pp. 105-114.

Fechtig, S.D., Boucek G.S., and Geiselman, E.E. (1998). Preliminary results of the effective information fusion for helmet mounted display technologies program. *Proceedings for the Third Annual Symposium and Exhibition on Situational Awareness in the Tactical Air Environment.* Naval Air Warfare Center - Aircraft Division. Patuxent River, MD., pp. 51-68.

Geiselman, E.E., Brickman, B.J., Hettinger, L.J., Hughes, T., DeVilbiss, C., and Haas, M.W. (1998). Methodology for evaluating off-axis helmet-mounted display ownship information. *Proceedings for the Third Annual Symposium and Exhibition on Situational Awareness in the Tactical Air Environment.* Naval Air Warfare Center - Aircraft Division. Patuxent River, MD., pp. 175-182.

Geiselman, E.E. and Osgood, R.K., (1994). Utility of off-boresight helmet-mounted symbology during a high angle airborne target acquisition task. *Helmet- and Head-Mounted Displays and Symbology Design Requirements.* Lewandowski, R.J., Stephens, W., and Haworth, L.A. (Eds.), The International Society for Optical Engineering. Bellingham, WA., pp. 328-338.

Geiselman, E.E. and Osgood, R.K. (1995). Head vs. aircraft oriented air-to-air target location symbology using a helmet-mounted display. *Helmet- and Head-Mounted Displays and Symbology Design Requirements II.* Lewandowski, R.J., Stephens, W., and Haworth, L.A. (Eds.), The International Society for Optical Engineering. Bellingham, WA., pp. 214-225.

Geiselman, E.E. and Tsou, B. H. (1996). Helmet-display resident target locator line symbology: an evaluation of vector length depiction. *Head-Mounted Displays.* Lewandowski, R.J., Haworth, L.A., Stephens, W., and Girolamo, H.J. (Eds.), The International Society for Optical Engineering. Bellingham, WA., pp. 233-244.

General Dynamics Corporation. (1992). Night Attack Program Pilot-Vehicle Interface Study. CCP 10113 Final Report.

Osgood, R.K., and Chapman, D.R. (1997). JSF integrated helmet audio-visual system technology demonstration results. *Head-Mounted Displays II.* Lewandowski, R.J., Haworth, L.A., Stephens, W., and Girolamo, H.J. (Eds.), The International Society for Optical Engineering. Bellingham, WA., pp. 332-335.

Osgood, R.K., Geiselman, E.E., and Calhoun C. (1991). Attitude maintenance using an off-boresight helmet-mounted display. *AGARD Conference Proceedings No. 1517*: Helmet Mounted Displays and Night Vision Goggles. pp. 14-1 - 14-7.